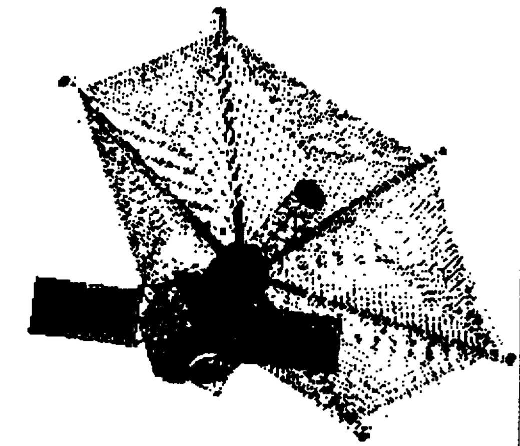
U.S. Space VLBI
Proposed Outreach Web Site

*This document reflects pages on an unapproved JPL web site. It is currently in DRAFT form for demonstration purposes only.

Space Very Long Baseline Interferometry :

Zooming In On Black Holes....



What does Space VLBI do?

We develop astronomical images of quasars using international radio interferometry. A key goal of Space VLBI is to use the long baselines between earth orbit earth, and the precisionof interferometry to allow us to create images as close as possible to the accretion disk around black holes, with as much detail as possible

How does Space VLBI work?

With Space VLBI we place a radio telescope in orbit and in conjunction with radio telescopes on earth to synthesize an apeture as big as the orbit of the spacecraft.

What do we see using Space VLBI?

We are able to see what we believe are evidence of massive black holes.

What are black holes?

A black hole is something so massive that it's escape velocity is greater than the speed of light, so no light can escape from it. No one has ever "seen" a black hole. However, we know that the space around a black hole is not actually black. Material is pulled toward a black hole by its strong gravity field. This forms a swirling accretion disk around a black hole. Enormous amounts of energy are released as the material slowly spirals into the black hole. Some of the material is shot out in radiating jets along the axis of rotation of disk. With Space VLBI, we have been able to "see" these jets, and we are trying to see closer in to see the accretion disks themselves.

Just Imagine....

We are able to point the spacecraft telescope at an astrophysical object such as a quasar, and we determine that we will look at the object for 12 hours. During that time, we send the signals received by the spacecraft down to the tracking stations on the ground. There the data is recorded on huge tape decks at rates of 1/8 Gbps up to 8 Gbps depending on the mission. At the same time on the ground radio telescopes are "staring" at the same object for the portion of 12 hours when they can see the object as the earth turns under them. They too are recording what they receive at the same high data rate on the same huge tape recorders.

Zooming In On Black Holes

Genesis of Space VLBI

The Program

The study of how VLBI might be pursued in space began in the late 1970's, when it was realized that the size of the earth was a serious limitation to the study of compact radio sources. By going to space, achieving angular resolution at radio wavelenghts that could not be obtained with VLBI systems that were limited by the size of the earth, important tests could not be made of quasar models.

The technology appeared to be within reach, and an early space VLBI concept, QUASAT, emerged as a joint project, involving both US and European scientists. In 1984, a workshop was held in Gross Enzerdorf, Austria, under joint sponsorship ofNASA and the European Space Agency (ESA). The principal conclusion of the workshop was that a VLBI station in space, telemetering its data to ground data stations, working in connection with ground-based radio telescopes, would give the opportunity to achieve angular resolution of a few tens of micro-arc-seconds, and could develop high-quality radio maps of many classes of radio sources. The ground telemetry stations would also function as the source of a stable local oscillator for the spacecraft, which needs a highly stable frequency reference. The Deep Space Network of NASA could play a vital role in both the frequency-locking system and data acquisition.

One outcome of the Gross Enzerdorf workshop was the convening, by COSPAR, of an ad hoc Committee on Space VLBI, to review and recommend procedures by which international collaboration on VLBI in space might be coordinated and promoted. In October 1985, the committee met in Budapest and recommended that the Inter-Agency Consultative Group (IACG) would be an appropriate body to coordinate VLBI activities in space. At the same time ESA convened a committee to explore the technical aspects of coordinating ground and space VLBI activities. At this stage both NASA and ESA were supporting preliminary studies of the QUASAT mission, with effective coordination between the two groups. The Soviet Union had also begun planning a mission with the clear intent to fly it as soon as the could; the mission was designated RadioAstron. In December 1985, the Soviets formed an international study team for the RadioAstron mission, holding the first meeting in Moscow. Subsequent meetings of this international committee were held in Budapest in May 1986 and in Moscow in December 1986. Thus, in 1986 there were three VLBI mission concepts under study: the NASA QUASAT mission, an ESA counterpart, and the Soviet RadioAston mission.

The QUASAT Proposals

In the 1987-88 time frame both NASA and ESA developed their versions of the QUASAT mission. The first proposal to be considered was the US version in response to an Explorer Announcement of Opportunity (AO). The mission failed to obtain approval in large measure because of its expense. The European version was submitted to ESA in October 1988 as a report on the Phase A Study. While ESA also found that the European version of QUASAT was beyond its budgetary allowance, the planning activities of both agencies had allowed all the necessary technical studies to advance to the point where no serious problems were anticipated. The QUASAT phase-A study is a clear statement of the scientific goals of VLBI in space, and a comprehensive study of the technical means by which the goals would be met.

The TDRSS Demonstrations

From 1986 to 1988 a series of space VLBI test demonstrations were carried out, using one of the two 4.9 meter antennas on the TDRSS satellite as a radio telescope, with the other being used as part of a closed-loop phase-measuring system. The first experiment took place at a frequency of 2.3 GHz. Two 64-meter ground radio telescopes were used for the other ends of the interferometer: the DSN antenna at Tidbinbilla, Australia, and the ISAS antenna at Usuda, Japan. With the successful completion of the 2.3 GHz phase of the demonstration (Levy et al, Science, 1986 and Ap J, 1989; Linefield et al, Ap J, 1989), it was decided that a 15 GHz experiment was both possible and desirable. THe observations were carried out in 1988m with success (Linfield et al, ApJ, 1990). The combination of the 2.3 GHz and 15 GHz experiements demonstrated beyond a doubt that space VLBI was technically feasible, and the fringes that were observed confirmed that the current hypothesis of bulk relativistic motion in radio-loud quasars were correct. Without bulk relativistic motion, Synchrotron self-Compton damping should have limited the source brightness temperature to 1012K, in which case only weaker fringes should have been observed.

The Radio Astron Mission

Informal exchanges between the Soviets and U.S. scientists continued through the RadioAstron International Science Council (RISC). By 1987, it was clear that continued participation in the RadioAstron project was advisable, but not possible because only pre-existing agreements on cooperation in space were being acted on by the U.S. at that time. The U.S. National Academy of Sciences had signed a cooperation agreement with the Soviet Academy of Sciences, however, so informal science exchanges continued with financial support from independent (non-U.S. government) sources; the exchanges kept NASA informed about the RadioAstron project. In 1989, NASA received permission to enter into new collaborations with the Russians. First negotiations with the RadioAstron mission were over frequency allocation tables, and NASA agreed to participate in the RadioAstron program.

The VSOP Mission

The Japanese radio astronomers had been actively engaged in VLBI studies from an early stage. At the 1984 Quasat Workshop in Gross Enzersdorf, the Japanese gave a brief communication, stating that the Japanese scientist at Nobeyama Radio observatory and at ISAS had been exploring what they might build and launch as a Japanese mission. They also participated in the first TDRSS demonstration in 1986 and 1987. In 1987 they submitted their first conceptual proposal. In 1992, a meeting was convened by the Japanese to start the formation of analogue organization to the RISC, the VSOP International Science Council (VISC).

History of Space VLBI

The history of radio astronomy has been marked by a continuous series of discoveries of new astrophysical phenomena. These discoveries have been instrumental in shaping the current view of the universe. The enormous power emitted by radio sources, galactic and extragalactic, was not foreseen in pre-radio astronomy days but it is now clear that high energy processes are common in astrophysics and that they occur in radio sources ranging from stellar to galactic dimensions. Radio astronomy played a vital role in the discovery of quasars, which are powerful active galactic nuclei. Galactic nuclei have been shown to be powerful centers of activity, in all likelihood associated with massive black holes. Radio images have shown ordered, collimated outflow of material from objects ranging in size from stars to galactic nuclei. In addition, the interstellar and circum-stellar masers observed at radio wavelengths demonstrate that dense gas clouds can exhibit phenomena with an entirely unexpected degree of order and coherence. The recent discovery of sources of maser emission in a ring about the nucleus of a nearby galaxy has shown that masers can also provide detailed information about the nuclear region of galaxies.

The advance of modern astrophysics has been marked by three principal instrumental themes: increased sensitivity, improved spectral coverage, and higher angular resolution. Despite the intrinsic limits imposed by diffraction at longer wavelengths, the greatest improvements in angular resolution have come in radio astronomy, where the advance of interferometric techniques has produced dramatic increases in the angular resolution of radio images. This has been because of longer interferometer baselines; VLBI, which combines the outputs of radio antennas located as far apart as an Earth diameter, marks the greatest advance achieved so far in angular resolution. Current global VLBI arrays with up to 18 elements and effective diameters of some 8000 km reach sub-milli-arcsecond angular resolution and are the largest telescopes which have ever looked into the depths of the universe. Accompanying this advance has been an increase in the quality of images, as characterized by their dynamic range, the ratio of the brightest to faintest reliable features. This increase has come as a result of better apeture plane (or uv plane) coverage and improved image construction algorithms.

The angular resolving power of the current global VLBI network at 1.35 cm wavelength (0.3 milli-arseconds or 300 micro-arcseconds) surpasses individual ground-based optical telescopes by more than three orders of magnitude and surpasses the Hubble Space Telescope by two orders of magnitude. This resolving power has led to many important discoveries, including apparent velocities in quasars and radio galaxies that exceed the speed of light, and highly collimated plasma jets in radio galaxies on scales of less than one parsec which are the baes of jets extending to several million parsecs, and a ring of maser sources in a galactic nucleus associated with matter accreting onto a massive central object. To a large extent it is the direct observational evidence from VLBI which has led to current ideas about compact "central engines" and bulk relativistic material motion in galactic nuclei. Within the home Galaxy, the powerful molecular masers, often associated with the star-formation process, have been shown to have complex spatial and velocity structure on very small scales which trace the winds of change in star formations. Active binary systems, such as the mass-transfer X-ray objects, exhibit outbursts of radio noise. Even the nucleus of the Galaxy is sufficiently compact to require study of VLBI techniques.

As the body of discoveries from VLBI has grown, it has become clear that in nearly every compact source observed at centimeter wavelengths, there remains spatial structure which is unresolved with the best angular resolution achievable with antennas on Earth. To explore the smallest structures and thereby observe on scales which are likely to be of great importance for the understanding of the central regions of quasars and galaxies, the role of molecular masers in star formation and stellar evolution, and flaring processes on stars, substantially higher resolution, high quality images are essential. This can only be achieved by placing a radio telescope in space observing in interferometric mode with Earth-based VLBI arrays. Space-to-ground VLBI is the next logical step in the development of radio interferometry. It will give angular resolutions better than for any other astronomical instrument operating at any wavelength in the next 20 years.

Space Very Long Baseline Interferometry

Educational Outreach

Superimposed Radio Image of Centaurus A

Space VLBI looks at the big questions...

How do matter and fields behave in extreme conditions?

How do galaxies evolve?

What is the shape and destiny of the universe?

What is dark matter?

How do matter and fields behave in extreme conditions?

Image the cores of active galactic nuclei at resolutions of 10 microarcseconds, studying the formation of energetic jets near their central black holes.

Image radio jets at resolution of light weeks, similar to the time scale of gamma-ray allowing a clean test of competing models for the physical processes in active galacti rise to the gamma-ray and radio emission.

Image relativistic jets in full polarization, to study the structure of their magnetic discriminate between electron-proton and electron positron jets.

Image water megamasers in external galaxies, to determine the physics and motions c material within 0.3 light years of the central black holes.

How do galaxies evolve?

Image radio jets at the centers of galaxies over a wide range of redshifts, to compar in galaxies in the early universe to those existing today.

Study the orgin, structure, and dynamics of gas disks that fuel the black holes in gal by means of observations of the circumnuclear water megamasers.

What is the shape and destiny of the universe?

Calibrate the scale of the cosmic distance ladder and the Hubble constant by making direct, geometric distance determinations of galaxies out to distances of 300 million light years, using measurements of water megamasers in galactic nuclei.

Determine the curvature of the universe by making measurements of radio sources sizes and proper motions as a function of redshift, particularly for sources that are 80% to 90% of the distance to the edge of the observable universe.

Image gravitational lenses at very high resolution, using time delay in the images to determine the Hubble constant.

What is dark matter?

Use high resolution images of gravitational lenses to improve the models of the distribution of matter in the lensing objects, hence making a direct measurement of the distribution of dark matter in these objects.

What are the life cycles of matter in the universe?

Image radio stars to model the exchange of matter between components in binary-star systems.

Make single-dish measurements of molecular oxygen in molecular clouds to mdel the temperature distribution within star-forming regions and close to the largest remaining uncertainty about their chemistry.

Did you know?

Light-year: A light year is the distance that light travels in one year. One light-year equals 10 trillion kilometers or a little over 5 trillion miles, approximately 250 million trips around the Earth at the Equator.

Galaxy: A collection of stars, dust and gas that holds together under its own gravitational attraction. There are countless galaxies in the universe and it is not uncommon for a galaxy to contain a billion, billion stars. We live in a moderate size galaxy.

Black Hole: A point in space which is infinitely small and infinitely dense, created when a massive object such as a heavy star or group of stars collapses upon itself and the forces of gravity. Once within the zone of influence of a black hole, nothing can escape, not even light.

Gamma-Ray: A highly energetic form of light which is not visible with the human eye. Gamma-rays have 3 million times more energy than the ultraviolet radiation taht causes sunburn and are produced in huge quantities at the centers of some galaxies that contain large black holes.

Radio-Radiation: A low energy form of light which is not visible with the human eye; it is the radiation that is used for radio and TV broadcast and communication. Radio radiation is also generated in large quantities close to some black holes at the centers of galaxies.

Space VLBI Outreach

Zooming In On Black Holes

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This is an artists rendition of what some astrophysicists believe is occuring in the hearts of some giant galaxies, millions to billions of light years distant. In the foreground we see a swirling disk of super hot material circling a massive black hole. The inner part of the disk, close to the black hole, is well-ordered, rapidly moving, and thin, while the outer, slower parts of the disk are more disordered and thicker. From the inner disk, magnetic fields which surround the black hole are sucking charged particles up from the surface of the disk as they swirl around the black hole, throwing them together and outward in a narrow jet, perpendicular to the disk, attaining speeds within a few percent of the speed of light. The material in the jets produces gamma-ray to radio radiation which can be observed with telescopes here at Earth.

In the background, we see smaller black hole-disk system which orbits the main system in the foreground. This system is less powerful and the jets it has created are much less impressive. However, the gravitational influence of the secondary blackhole can cause the foreground jet to bend as it moves away from its black hole and disk.

The features that we see in this picture are thousands to millions time finer in detail than we can see at the moment with even the highest resolution telescopes available, including current space VLBI missions. The artist has conceptualized this image based on the best theoretical models which explore how jets might be produced from black holes and disks. The eventual goal of Space VLBI missions is to produce images of the disks and jets in distant galaxies at high enough resolution to test the theories on which this picture are based, to see if they are correct.

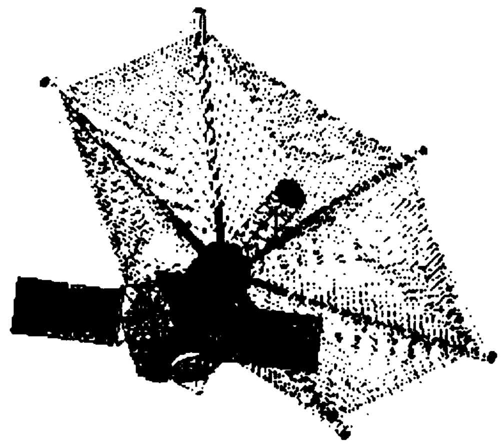
For more information on black holes, please see

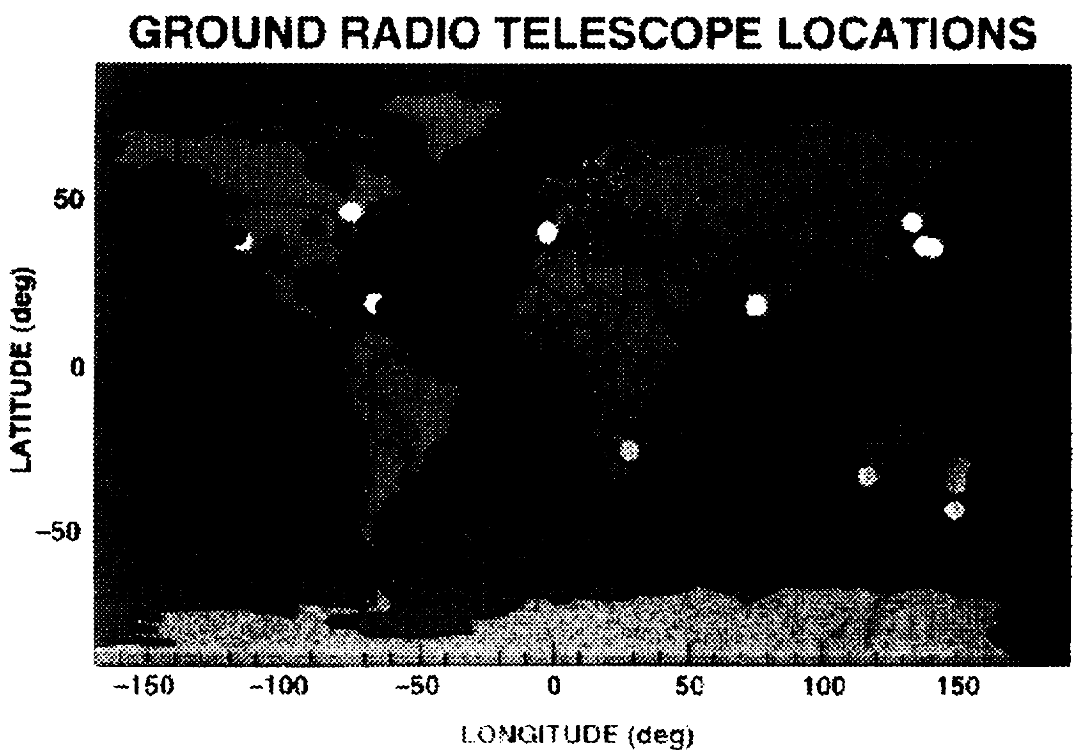
SEU Forum

How does VSOP look at black holes?

How do we look at blackholes?

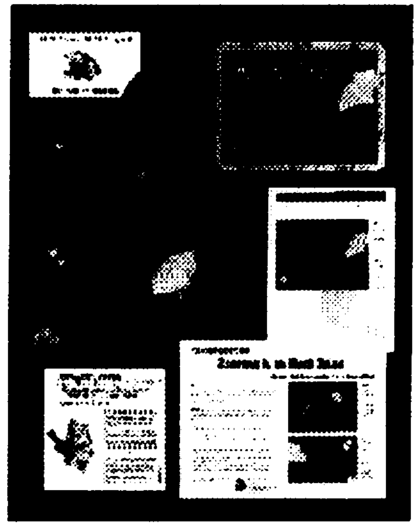
This is a new type of astronomy mission that uses a combination of satellite-and Earth-based radio antennas to create a telescope larger than Earth. The VLBI Space Observatory Programme(VSOP) a project of the Institute of Space and Astronautical Science (ISAS), launched the 8-meter spacecraft into elliptical high earth orbit in February 1997. This first radio telescope in space observes objects with a number of ground radio telescopes located around the world.





Educational Outreach Products

U.S. Space Very Long Baseline Interferometry



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Space VLBI Outreach Page

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Future Space VLBI Missions

There are a growing number of Space VLBI missions being considered at the Jet Propulsion Laboratory.

- **ALFA**
- JPL Midex Class Proposal:is a JPL Mid-Ex Class proposal by JPL to be submitted for approval in 2000
- **VSOP2**
- is an ongoing advanced mission study at the Japanese space agency ISAS. It is expected to be a follow-on mission to the on going Japanese Space VLBI mission VSOP.
- **ARISE**
- is a U.S. proposal of large Space VLBI spacecraft planned for launch in 2008 to 2010.

Beyond ARISE the future missions are not predictable. Scientist in Eurpoe are considering the construction of a large antenna erected by astronauts on-board the Space Station Freedom, then kicked into orbit. In Japan, there has been talk of a cluster of large precise antennas in orbit together. As these mission concepts evolve they will be added to this page. Return to Space VLBI Home Page